

The Future of Simulation

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SUMMARY

This short paper outlines some of the author's thoughts on the "future of simulation." After a brief motivation for the article and a recounting of the history of simulation, four major themes are explored: convergent simulations, serious games and simulation, human-simulator interfaces, and computing technology. The article concludes with a "vision" of what a future simulation might be.

INTRODUCTION

Predicting the future has only one certainty—the more specific the prediction, the more likely it is to be wrong. This caveat applies to the contents of this brief paper.

There are a number of past examples in which individuals (usually in panels) were asked to predict the "Future of Simulation". For many years, the annual Winter Simulation Conference¹ has routinely offered a panel discussion on this topic. In most cases the panelists dealt with "simulation in the small" not "simulation in the large". In this paper we will deal primarily with "simulation in the large", moreover, the paper will take the liberty of going beyond the normal boundaries of simulation and also deal with the human-simulator interface, some of the technological underpinnings of simulation, and the relationship(s) of simulation to entertainment.

The future of simulation will, in this author's opinion, be determined, not by a systematic, well-coordinated effort of a body of academic researchers, rather it will be determined by forces beyond the control of any individual or small group of researchers—world events and public demand for entertainment will play the predominate role in shaping the future of simulation.

Finally, a disclaimer is in order: the ideas presented here, unless specifically cited as those of another, are the author's own, and he will graciously accept the ridicule of the readers, both now and when he is proven wrong.

¹ See, for example, <http://www.wintersim.org/prog03.htm#FS>

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A BRIEF HISTORY OF SIMULATION

By any measure, simulation has a long history. Humans are natural “simulationists”. Young children will make or use models (dolls and other toys) to execute a simulation (play). Games such as Chess (in the West) and Go (in the East) have served for hundreds of years as simulations of warfare. There is ample evidence in the historic record that live simulation has been employed for at least two thousand years.² Formal use of “wargaming” by the military became common in the nineteenth century. The beginning of the modern era of simulation, however, is usually associated with the advent of flight simulation in the early twentieth century. Computer-based simulation began in the 1950’s and, of course, is now commonplace. In almost every case simulation has been a response to a perceived problem (e.g., plane crashes due to pilot inexperience or the need for improved decision making). In the past few decades we have seen the advent of distributed simulation³ and the development of virtual environments⁴ as an alternative human-simulator interface.

CONVERGENT SIMULATIONS⁵

A distinct thread in the evolution of simulation is *convergence*. Historically, distinct simulation approaches (e.g., discrete and continuous) have been conceived and applications developed in a relatively independent manner. The demand for simulation applications that serve more than one audience and/or more than one purpose has led to the convergence of heretofore distinct simulation approaches. A current example of significant interest to the military is the convergence of live, virtual, and constructive (LVC) simulation within the Joint National Training Capability (JNTC)⁶. Traditionally, the military has used live simulation as a primary means of training. With the high cost of such training and the growing shortage of adequate space for its conduct, constructive simulation and, more recently, virtual simulation have become increasingly important. The convergence of LVC simulation provides the military (and others) with the ability to “mix and match” simulation methodologies to meet both the training objectives of the commander and the constraints (time, space, cost) imposed by the training context. The ultimate goal of the JNTC effort is to deliver, for the commander, the needed training with the optimal mix of LVC any place, any time.

SERIOUS GAMES⁷

Modern computer-based games are often predicated on the marriage of simulation (and computer graphics) and entertainment. Such games have been wildly successful and have led to the production of very low-cost delivery platforms that are characterized by high performance computing and graphics. Profits are derived from economy of scale, driven by the huge demand for products. Many within the military have watched this

² See, for example, Josephus. *The Wars of the Jews or the History of the Destruction of Jerusalem*, Book III, Chap. 5, Sect. 1. (circa 70 A.D.)

³ See, for example, E.A. Alluisi. The Development of Technology for Collective Training: SIMNET, a Case History. *Human Factors* 33 (3), pp. 343-362 (1991).

⁴ See, for example, N. Durlach and A. Mavor (Editors). *Virtual Reality: Scientific and Technological Challenges*. Washington, DC: National Academy Press, 1995.

⁵ This was a term used by the author for a presentation: Convergent Simulations: Integrating Deterministic and Interactive Systems. Human Performance and Simulation Workshop, Alexandria, Virginia, July 30, 1997.

⁶ See http://www.jfcom.mil/about/fact_jntc.htm

⁷ Information on the Serious Games Summit, one of the current venues for discussing serious games, can be found at <http://www.seriousgames.org/index2.html>

development and have recognized the potential of game platforms (and the underlying game engines) as a means of delivering, again at a low cost, games that can provide some types of training. The challenges lie in (1) the insertion of appropriate instructional design methods into game development, (2) the demonstration of the efficacy of game-based training, and (3) recognition that some (many?) training applications, even in the military, may have limited audience size or require frequent updating.

A current example of a game-based training system is Pulse!!⁸, under development by Texas A&M University-Corpus Christi and Breakaway Games, led by Claudia Johnston. This game/trainer is using a commercial game engine to build scenarios that deal with trauma care. The graphics and capabilities of the system are on a par with the best games available today.

HUMAN-SIMULATOR INTERFACES

Flight simulation has typically used replicas of aircraft cockpits as the interface between the human and the simulation. Products like Microsoft Flight Simulator™⁹ have, in the interest of accessibility, developed very high-fidelity simulators with interfaces based on the keyboard/mouse with the possible addition of other relatively low-cost interface devices. Future simulations will most likely rely on *adaptive interfaces*—interfaces that are reasonably generic, at least within a given domain, and that can be readily adapted to a range of simulations. To accomplish this capability, one needs access to a variety of displays: visual (three-dimensional, wide field-of-view), haptic, vestibular, olfactory, and (perhaps) gustatory. In the intermediate term, we can expect display *devices* that couple directly or closely to the human sensory system. In the visual domain an example of this type of device is the retinal display¹⁰, under development (and available in limited capability versions) from Microvision¹¹. The concept is simple: use one or more color lasers and a raster device to “write” images directly on the human retina. Sophisticated, but highly constrained, haptic displays are also commercially available¹². Vestibular displays¹³ (e.g., motion bases) are also available as are a few examples of olfactory displays¹⁴. While serious engineering is still needed, there is the potential for these displays to mature to the point where their cost, ease of integration, and robustness is sufficient to serve as interfaces to simulations in a variety of application areas.¹⁵

In the longer term, we will see the introduction of the means to directly connect to the human sensory system. At least one example has been in place for some time—a vestibular display¹⁶ developed by the U.S. Air Force. This display directly stimulates the human vestibular system. One can conceive of a family of such devices

⁸ For a press release from Breakaway Games, see <http://www.breakawaygames.com/news/2005/pulse.shtml>

⁹ See <http://www.microsoft.com/games/flightsimulator/>

¹⁰ See, for example, http://www.cs.nps.navy.mil/people/faculty/capps/4473/projects/fiambolis/vrd/vrd_full.html

¹¹ See <http://www.microvision.com/>

¹² See, for example, <http://www.sensable.com/>

¹³ See, for example, <http://www.inmotionsimulation.com/>

¹⁴ For pointers to examples of olfactory displays, see Donald A. Washburn and Lauriann M. Jones. Could Olfactory Displays Improve Data Visualization? *Computers in Science and Engineering* 6 (6), pp. 80-83 (November/December, 2004).

¹⁵ For a somewhat more discursive discussion of multi-sensory display technologies, see R.B. Loftin. Multisensory Perception: Beyond the Visual in Visualization. *Computers in Science and Engineering* 5(4), pp. 565-58 (July/August, 2003).

¹⁶ J.D. Cress, L.J. Hettinger, J.A. Cunningham, G.E. Riccio, M.W. Haas, and G.R. McMillan. Integrating Vestibular Displays for VE and Airborne Applications. *IEEE Computer Graphics and Applications* 17 (6), pp. 46-52 (November, 1997).

that are directly coupled to the human sensory system and, in principle, could provide the ultimate display capability (with all due respect to Ivan Sutherland)¹⁷.

COMPUTING TECHNOLOGY

Over the past twenty years we have seen an extraordinary evolution of computing capability. Nonetheless, the simulation community has often been ahead of the curve. That is, as soon as we can simulate, in real time, 100k entities, the community demands that we simulate 500k or 1,000k entities with the same speed. The current frontiers of computing technology are focused on quantum computing¹⁸ and biological computing¹⁹. In either case, there is the potential for several orders of magnitude improvement in computing capability with a concomitant reduction in the size and power requirements of the devices. This opens the opportunity for essentially unlimited entity count and performance on the compute side while enabling simulation to become truly portable.

THE FUTURE OF SIMULATION

How can we envision the influence of developments, along the four dimensions explored above, in the creation of a future simulation? First, let us focus on a specific application of simulation: training. With this in mind, we must think in terms of a seamless mix (or convergence) of live, virtual, and constructive elements with the fewest participants in the live and the most in the constructive domains of the simulation. However, *from the users' perspectives*, they will not be able to identify which entities are real participants in a real-world setting, which are real participants in a virtual environment, and which are computer-generated entities in a virtual environment. Second, we can assume that we will take advantage of advanced computing technologies and serious gaming techniques that provide the real participants in the virtual environment with a world “virtually” indistinguishable from the real world in terms of its sensory fidelity and interactive responsiveness. Third, the users will interact with both virtual environments using interfaces that are tightly integrated with their own sensory systems and that do not intrude in ways that render the virtual world any less believable than the real world. Finally (and again) computing technology will allow essentially unlimited entities in both the virtual and constructive components while enabling truly adaptive capabilities in terms of the evolution of the simulation in response to user actions. The resulting simulation will, if properly designed and executed, provide the ultimate in training efficacy, any place, any time.

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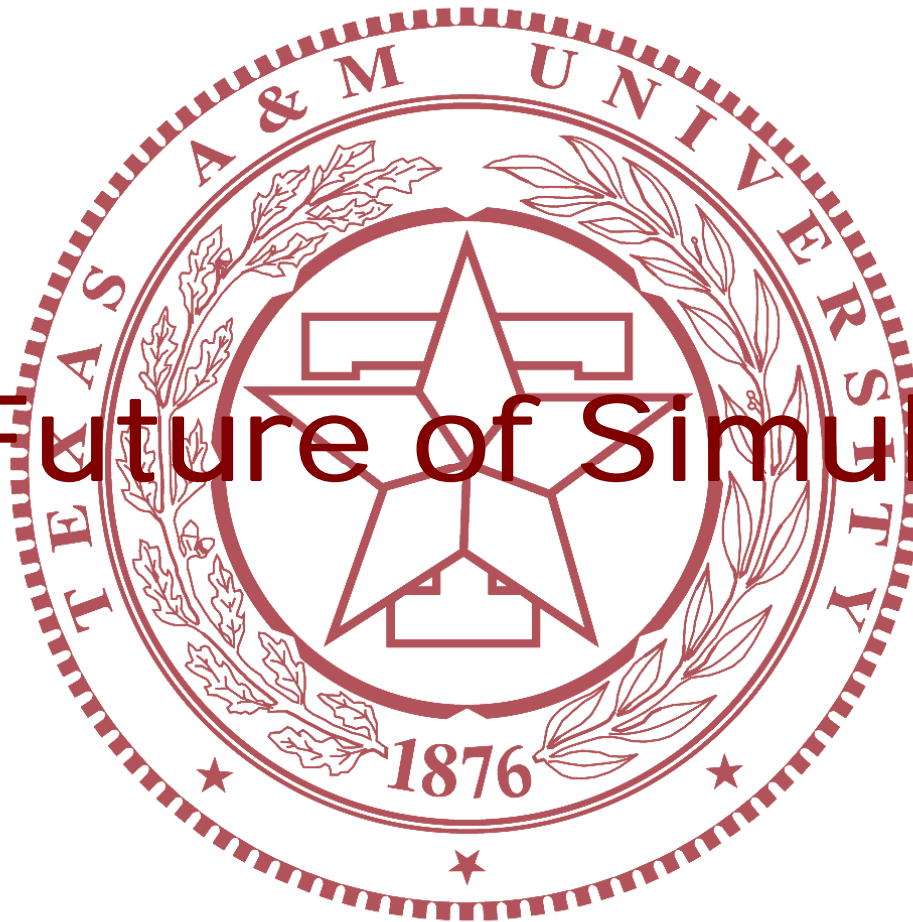
The author was tasked, almost fifteen years ago, by Mark Gersh, then at Headquarters, National Aeronautics and Space Administration (NASA), with developing a white paper on the “future of training”. I am indebted to Mark for the initial stimulus to think about such things as directly coupling humans to simulators. I am also grateful for the support of Robert T. (Bob) Savely of the NASA/Johnson Space Center in carrying out that task.

¹⁷ Sutherland, I. E. The Ultimate Display. In *Proceedings of the International Federation of Information Processing Congress 2*, pp. 506-508 (1965).

¹⁸ See, for example, Mika Hirvensalo. *Quantum Computing*. Second Edition. Berlin: Springer-Verlag, 2004.

¹⁹ See, for example, Leandro N. de Castro and Fernando J. Von Zuben. *Recent Developments in Biologically Inspired Computing*. Hershey, Pennsylvania: Idea Group Publishing, 2005.

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Author's Background

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A Caveat

Predicting the future has only one certainty—the more specific the prediction, the more likely it is to be wrong.

Outline

- Introduction
- A Selective History of Simulation
- Convergent Simulations
- Serious Games
- Human-Simulator Interfaces
- Computing Technology
- The Future of Simulation

A Selective History of Simulation

- Wargaming (Kriegspiel)
- Flight Simulation

Wargaming (1 of 14)

- Peter P. Perla. *The Art of Wargaming*. Annapolis, Maryland: Naval Institute Press, 1990.
- Alfred H. Hausrath. *Venture Simulation in War, Business, and Politics*. New York: McGraw-Hill, 1971.

Wargaming (2 of 14)

- John P. Young. *History and Bibliography of Wargaming*. Washington, DC: Department of the Army, 1957.

Wargaming (3 of 14)

- In the beginning . . . games based on warfighting
 - Chess (West)
 - Go (East)
- The rise of formal military organizations leads to simulation for planning and training.

Wargaming (4 of 14)

“. . . their exercises unbloody battles,
and their battles bloody exercises.”

Josephus. *The Wars of the Jews or the History of the Destruction of Jerusalem*, Book III, Chap. 5, Sect. 1 (circa 70 AD)

Wargaming (5 of 14)

- 1781: Clerk's (England) use of model ships to examine placement of combatants.
- 1811: von Reisswitz's (the first) (Prussian War Counselor at Breslau) develops a "sand table".

Wargaming (6 of 14)

- 1824: von Reisswitz (the second)—a Prussian Lieutenant—adapts his father's game to paper maps; von Muffling (Prussian Chief of Staff) orders the use of wargames throughout the Prussian Army.
- 1837: von Moltke (Prussian General) becomes Chief of Staff of Prussian Army and increases the use of wargames.

Wargaming (7 of 14)

- von Moltke introduces the “Staff Ride”.
- Prussian success in battle leads others to adopt wargaming.
- 1883: Livermore (Major, Corps of Engineers) improves Prussian attrition models (using historical data) and urges the use of wargaming in the United States; General William T. Sherman, Chief of Staff, discourages use of wargaming.

Wargaming (8 of 14)

- William McCarty Little initiates the use of wargaming at the Naval War College.
- 1887: first U.S. Army-Navy field exercise based on a wargame (Little and Livermore)
- 1905 – 1918: Wargaming significantly influences policy and doctrine but shows its lack of scope.

Wargaming (9 of 14)

- 1929: George Kenney (Captain, U.S. Army Air Corps) developed the first tri-service wargame, including logistics.
- Extensive wargaming done by the U.S. Navy and Marine Corps in the inter-war period.
- All combatants make extensive use of wargames during World War II.

Wargaming (10 of 14)

- The U.S. evolves a combination of constructive and live simulation in the pre-World-War-II era under the leadership of George C. Marshall.
- Wargaming declines in importance in the years after the end of World War II.
- 1950's: computers are applied to wargaming.

Wargaming (11 of 14)

- 1958: Harvard Business Review suggested applying wargaming to business planning
- 1960's: Wargames began to include political issues (*cf*, Bay of Pigs); efforts were made to develop models that were not strictly attrition based
- 1971: Navy's Top Gun School opens

Wargaming (12 of 14)

- 1974: Air Force's Fighter Weapons School opens 1974: Army purchased Fire Fight
- 1975: Navy's Command Readiness Program established
- 1980: National Training Center opens
- 1982: National Defense University opens its wargaming center

Wargaming (13 of 14)

- 1990: Executive Council on Modeling and Simulation established in U.S. Department of Defense
- 1991: Defense Modeling and Simulation Office established
- 1990's: Huge investments made in models and simulations; virtual simulations become commonplace

Wargaming (14 of 14)

- 2002: \$235M Millennium Challenge '02 Experiment
- 2003 Joint National Training Capability launched

Flight Simulation (1 of 8)

- *Proceedings [of the] Second Flight Simulation Symposium, 16-17 May 1973 (ASIN: 090340902X)*
- *50 years of Flight Simulation: Conference Proceedings. Piccadilly Hotel, Piccadilly, London, England, April 23-25, 1979. (ASIN: 0904999459)*

Flight Simulation (2 of 8)

- *Proceedings of the AIAA Flight Simulation Technology Conference* (November 1987). Washington, DC: American Institute of Aeronautics & Astronautics
- J.M. Rolfe and K. J. Staples (Editors). *Flight Simulation*. Cambridge: Cambridge University Press, 1988. (ISBN. 0 521 35751)

Flight Simulation (3 of 8)

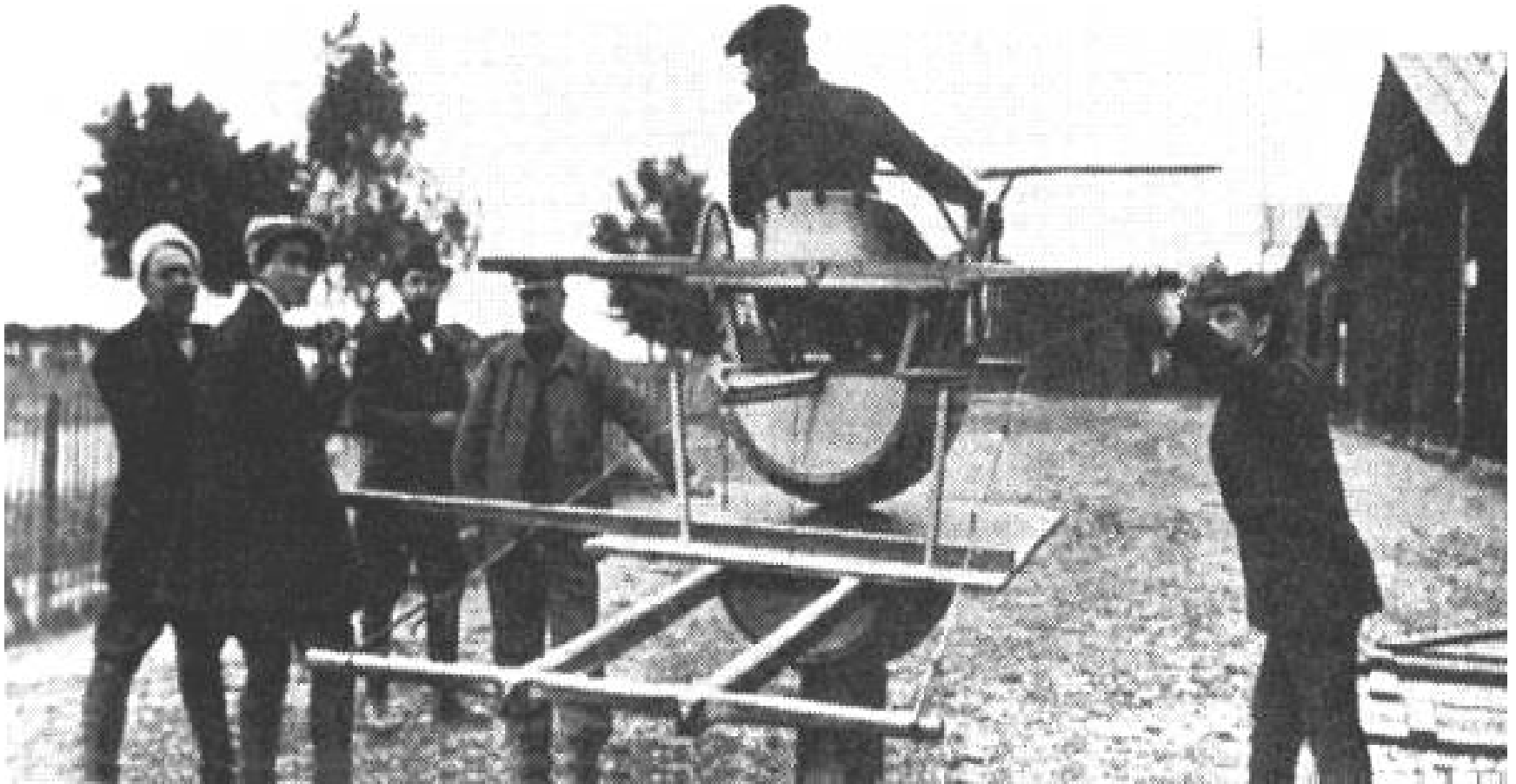
- Early manned gliders and the first powered aircraft were themselves used, on the ground, as “simulators” for training novice pilots.
- Other methods used moving aircraft supported by balloons, overhead gantries, or railway bogies.

Flight Simulation (4 of 8)

- Loss of life and aircraft led to a growth of interest in simulators for training.

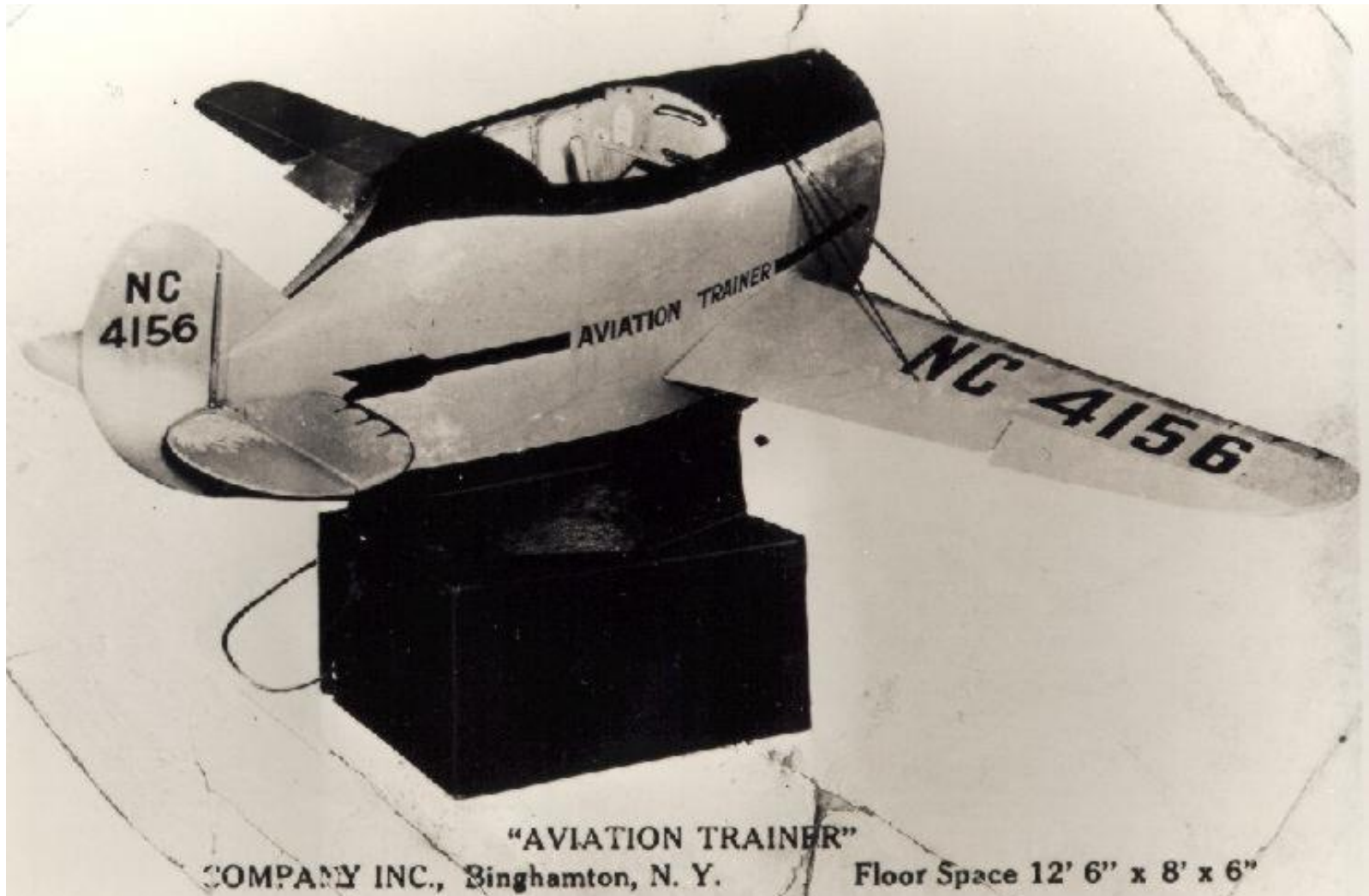
Flight Simulation (5 of 8)

1910 Simulator



Flight Simulation (6 of 8)

The Link Aviation Trainer



Flight Simulation (7 of 8)

The Link Aviation Trainer (IFR)



Flight Simulation (8 of 8)



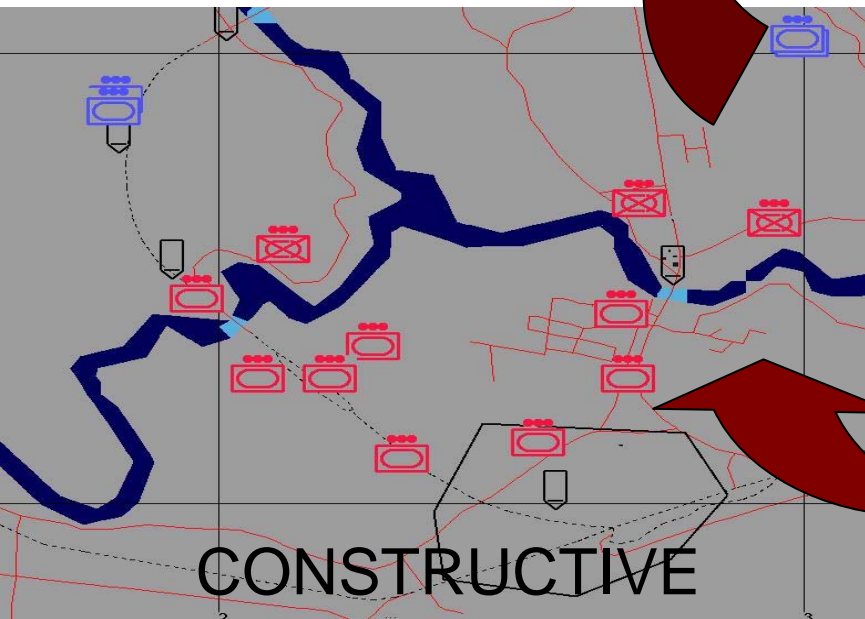
Where are we now?

- Flight simulation is so good that it enables commercial pilots to confidently fly a new airplane for the first time with passengers on board.
- We are approaching the level of near indistinguishability of the simulator from the real thing.
- Low-cost simulators are widely available.

Convergent Simulations

- Simulation Genres
 - Live
 - Virtual
 - Constructive
- Goal: Convergence into a “Seamless” Simulation Environment
- Millennium Challenge '02
- Joint National Training Capability

Live-Virtual-Constructive Simulation Integration



Millennium Challenge '02

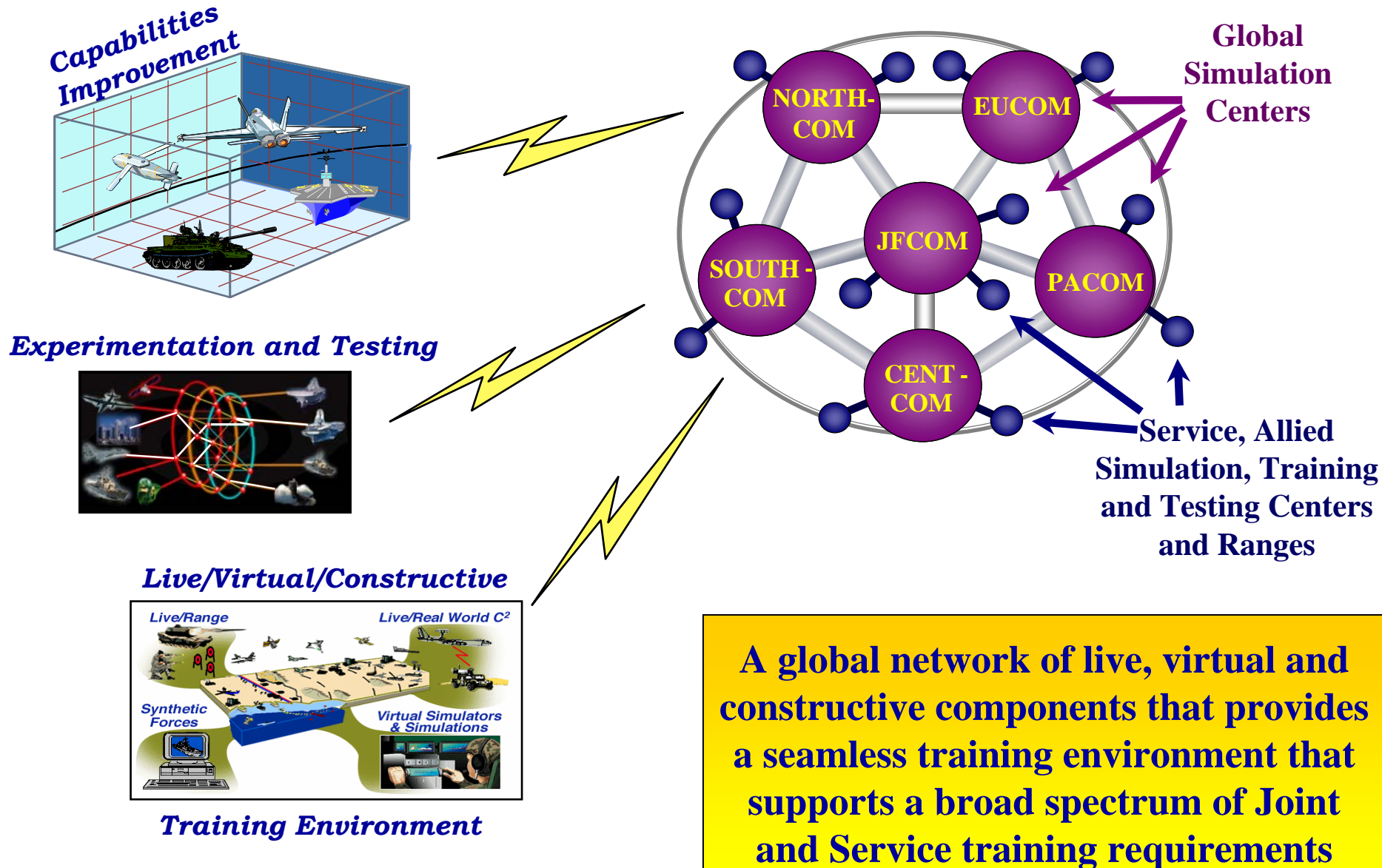
Overview Video

Millennium Challenge '02

Modeling & Simulation

Video

Joint National Training Capability



I/ITSEC '05
Joint Virtual Training Special Event
Video

Serious Games

- Rapid Evolution of Single- and Multi-Player Games for Entertainment
- Some Military Venues
 - Full Spectrum Warrior (ICT & Pandemic)
 - America's Army (U.S. Army & NPS)
 - Pulse!! (Texas A&M-Corpus Christi & Breakaway)
- Conferences
 - Serious Games Summit
- Bob Stone's Monday Paper (#8)



Pulse!!

Demonstration

Serious Games

- Near-Term Issues
 - Overcoming Perception
 - Proprietary Game Engines
 - Compute/Display Platforms
- Intermediate-Term Issues
 - Design for Training/Learning
 - Serious Evaluations

Human-Simulator Interfaces

- Visual
- Auditory
- Haptic
- Vestibular
- Olfactory
- Gustatory
- Future Interfaces

Interface Issues

- Different levels of technological maturity of displays, even within one modality
- Integration of hardware and software
- Lack of a theory of multi-sensory perception
 - What sense or senses are necessary (and/or “nice to have”) for what application?
 - Interdependencies and “leveraging”?

Further Reading

- R.B. Loftin. Multisensory Perception: Beyond the Visual in Visualization. *Computers in Science and Engineering* 5(4), pp. 565-68, July/August, 2003.
- Soldier CATT Technology Assessment (ARI)
- Intelligent Tutoring Systems Research Issues (US Army RDEC)

Future Interfaces

- Near- and Intermediate-Term
 - Technical Improvements (e.g., fidelity)
 - Tighter Coupling to the User
 - Problems: Markets? Mass Production?
 - Adaptive Interfaces
- Long-Term
 - Direct Coupling to Human Sensory System and/or Brain
 - Problems: Acceptance? Safety?

Adaptive Interfaces

- Provides the optimal display(s), given the user and the purpose of the simulation
- Can dynamically change display modalities as needed during simulation
- Incorporates Intelligent Tutoring System technology to individualize the simulation experience for each user to achieve optimal training efficacy

Retinal Display

Current Model

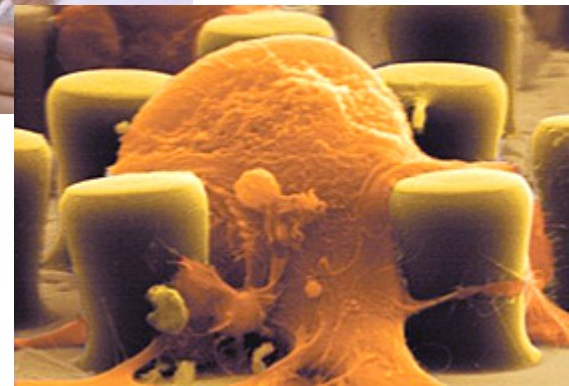
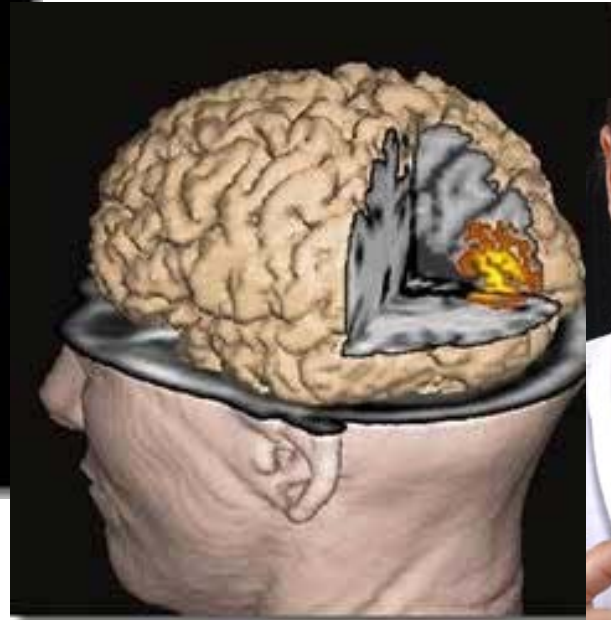
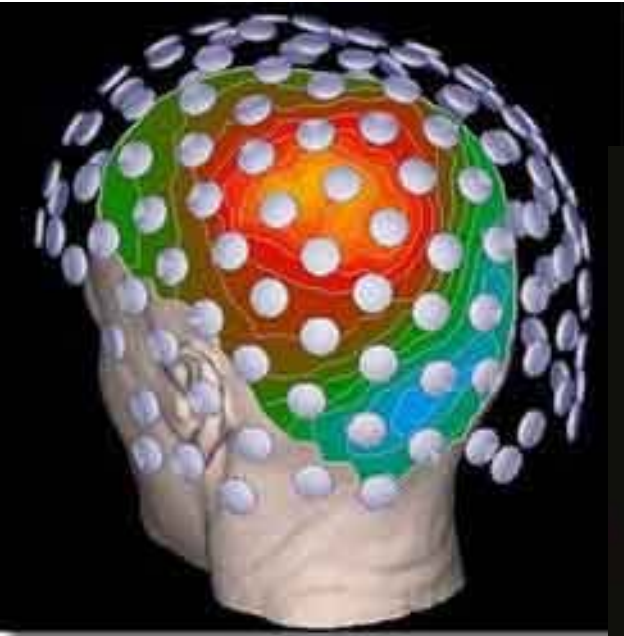


Future Concept



Microvision

Future Interfaces

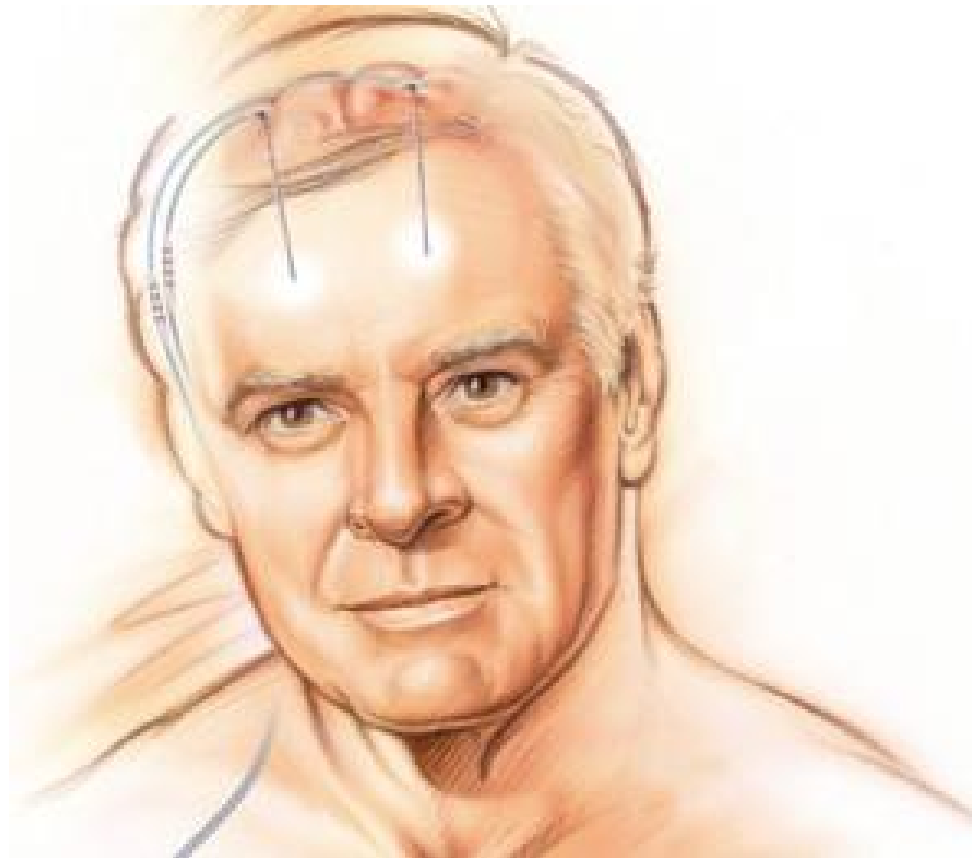


Future Interfaces

The design of effective human-machine interfaces is one of the more challenging and exciting issues facing engineers today.... As part of our research on multimodal VE interfaces, [we] supplemented a visual display with direct vestibular stimulation to add tilting and rolling sensations to training VEs.

J.D. Cress, L.J. Hettinger, J.A. Cunningham, G.E. Riccio, M.W. Haas, and G.R. McMillan. Integrating Vestibular Displays for VE and Airborne Applications. *IEEE Computer Graphics and Applications* 17 (6), pp. 46-52 (November, 1997).

Future Interfaces



Future Interfaces

The union of human and machine is well on its way. Almost every part of the body can already be enhanced or replaced, even some of our brain functions. Subminiature drug delivery systems can now precisely target tumors or individual cells. Within two to three decades, our brains will have been "reverse-engineered": nanobots will give us full-immersion virtual reality and direct brain connection with the Internet. Soon after, we will vastly expand our intellect as we merge our biological brains with non-biological intelligence.

Ray Kurzweil
We Are Becoming Cyborgs

Computing Technology

- Simulation (Virtual and Constructive) is demanding!
- Virtual Simulation has huge demands in terms of latency and sensory fidelity.
- Constructive Simulation has demands in terms of entity count and model fidelity.
- Good News:
 - Computing power continues to grow
 - New technologies (quantum and biological computing) promise significant performance improvements and decreased power/volume.

The Future of Simulation

- Multi-purpose (planning, training, analysis, . . .), scalable, multi-resolution
- Seamless (blend of live, virtual, and constructive) to the user
- Uses game technology
- Has an adaptive interface, ultimately tightly coupled to our sensory system
- Virtually unlimited computing power

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